the Energy to Lead

Fuel Quality Critical Issues

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Industry Need/Business Value

- Critical time for natural gas in transportation market; transitioning to high-volume users
- Stakes are higher; downtime in large fleets is not accepted
- Large fleets and station providers have some serious concerns; costing them millions of dollars in revenue:
  - >5,500 NGVs, largest commercial CNG fleet in US
  - ~150 Class 6-8 NGVs; Champion for Long-haul CNG trucks
  - A key supplier to light-duty market
  - Large supplier of HD engines
  - Significant supplier of on-board fuel systems
  - Primary station owner/operator

Heavy Hydrocarbons (HHCs)

- New make-up of gas supply along with typical fuel quality concerns lead to possible misperceptions (NGLs, Oil carry-over, moisture, etc.)
- Filtration of heavy hydrocarbons (HHCs) in the station and vehicle is difficult especially in vapor phase
- Accurate method to capture and analyze (HHCs) is difficult
  - No ASME or ASTM method for quantifying oil in gas sample
  - HHCs “drop-out” of gas when taking samples
  - Analysis often performed on liquids from station & vehicle filters
- Lack of testing protocol leads to inconsistent/misleading results and “finger pointing” between fleet, vehicle supplier, station provider, and utility

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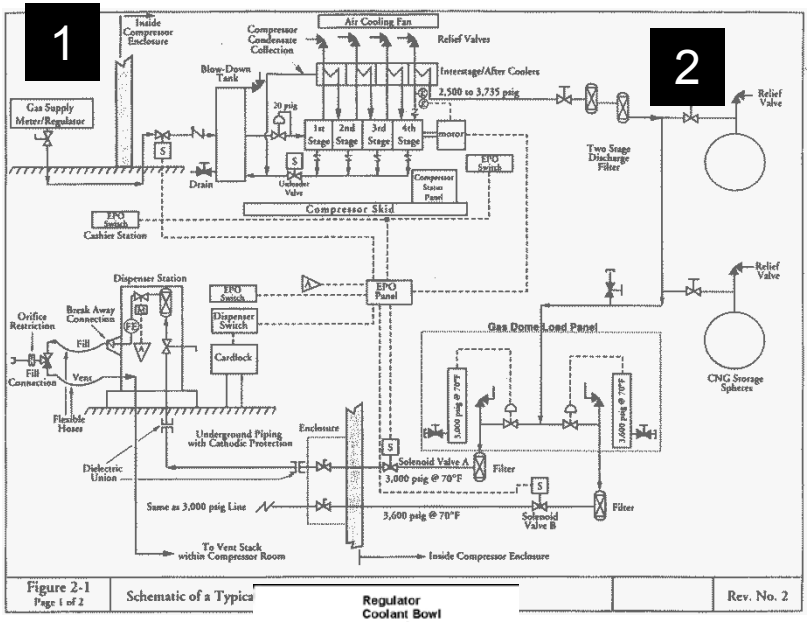
NGV Station & Vehicle Systems

1



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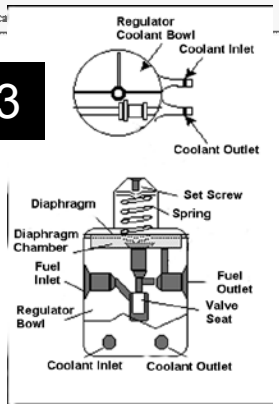
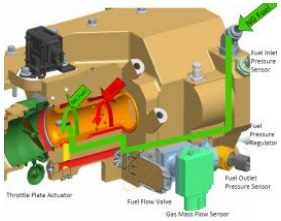




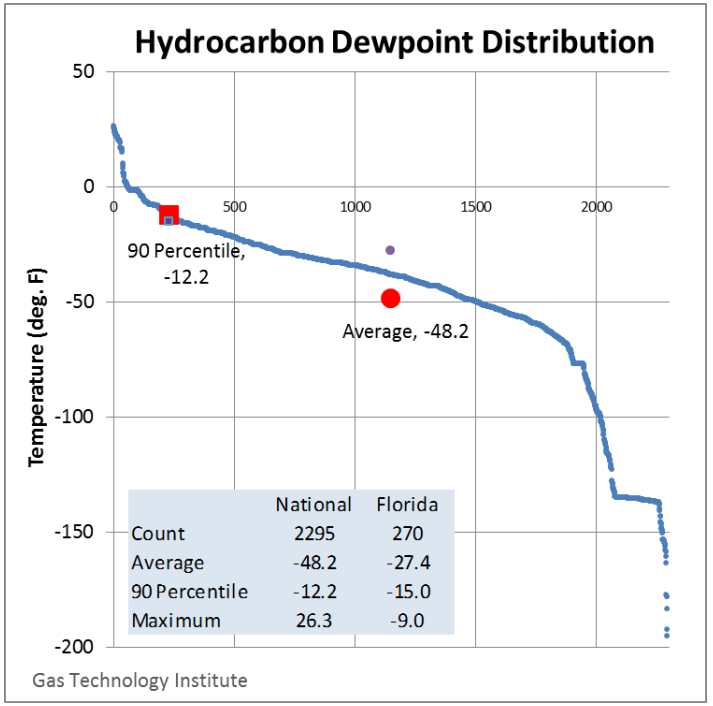
1: Station Supply.
What is the incoming gas quality?

2: Station Post-Compression.
What is gas temperature going into the oil filters? How much oil/liquids are going into the filters? Is the liquid collected oil and/or NGLs? How much oil/liquids is passing through as vapor/aerosols? What options to increase capture efficiency (e.g., adsorbents, lower temperature)?

3: Vehicle Post-Pressure Regulation.
What is gas temperature at the vehicle regulator outlet? How much oil/liquids are going in to the filters (e.g., lb/MMSCF)? Is the liquid collected oil and/or NGLs? Can the outlet temperature be raised? What options to increase capture efficiency (e.g., adsorbents)?

National Data

- Comprehensive survey has not been conducted since GTI/GRI in 1992
- Limited recent 2013 assessments by GTI
- Data show reasonably low hydrocarbon dew points
  - Average: -48°F (2295 measurements)
  - 90th Percentile: -12°F
  - Maximum: 26°F

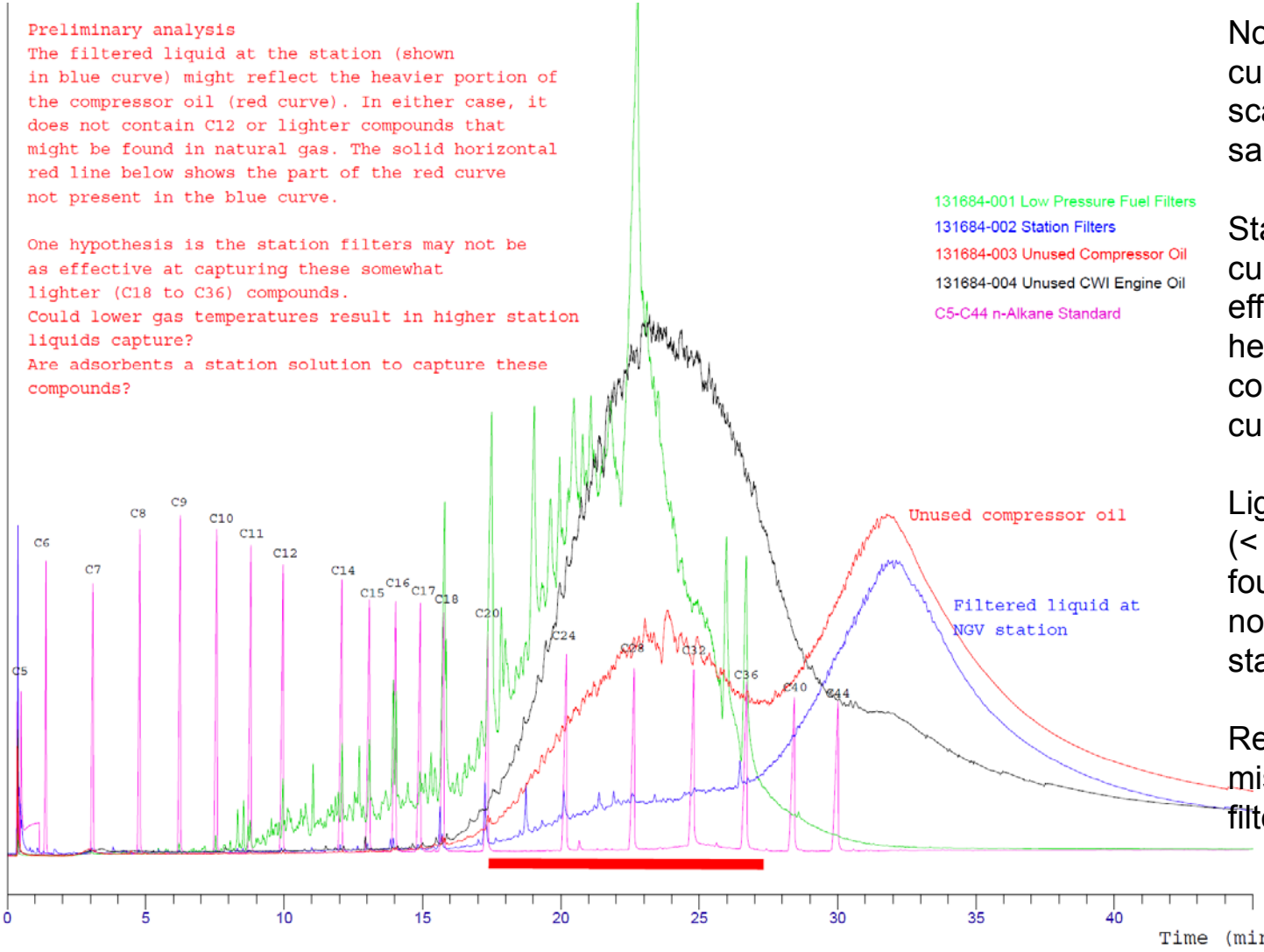


gti	Number of Sites	Number of Samples	Methane	Ethane	Propane	N2	CO2	Higher Heating Value (BTU/scf)	Specific Gravity	Wobbe Number (BTU/scf)	Hydro-carbon Dew Point (°F)
2013 Survey Average	23	4551	95.27	2.793	0.2941	0.582	0.864	1030.7	0.586	1344.6	-41.1
1992 Survey Average	41	6811	92.95	3.210	0.6636	1.803	0.845	1027.9	0.599	1328.8	--
Change			2.32	-0.416	-0.369	-1.221	0.020	2.8	-0.013	15.9	

Station Post-Compression

2: Station Post-Compression

What is gas temperature going into the oil filters?
How much oil/liquids are going in to the filters?
Is the liquid collected oil and/or NGLs?
How much oil/liquids is passing through as vapor/aerosols?
What options to increase capture efficiency (e.g., adsorbents, lower temperature)?



Note the size of the curve is an artifact of scaling to 100% of the sample.

Station filters (blue curve) appear to be effectively capturing heavier portion of compressor oil (red curve)

Lighter compounds (< C-12) typically found in nat. gas are not appearing in station filters.

Red bar region missing from station filters

Vehicle Post-Pressure Regulation

3: Vehicle Post-Pressure Regulation.
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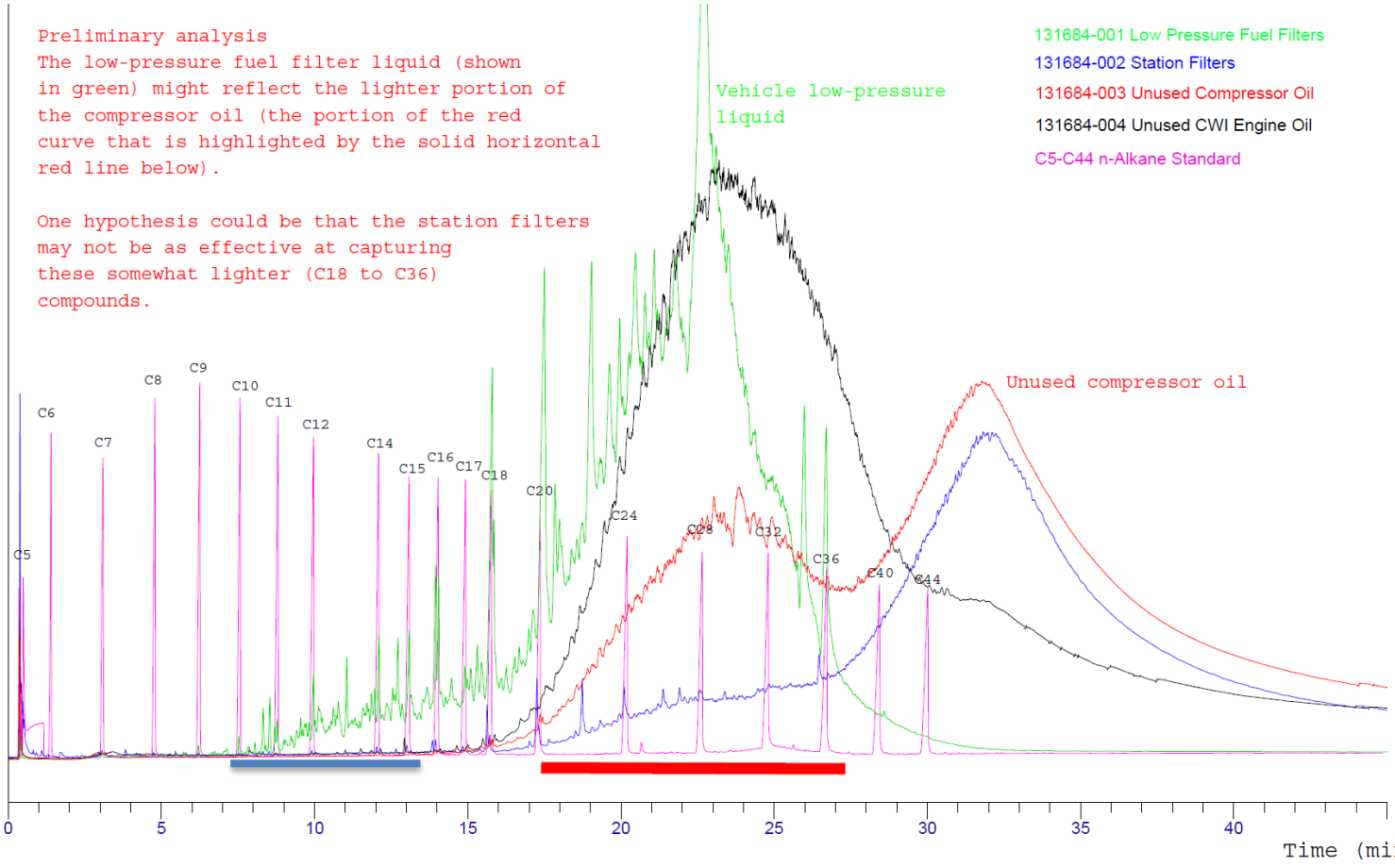


The vehicle filter (green curve) appears to reflect a portion of compressor oil curve – the difference between the red and blue curves (red bar zone).

Note the size of the green curve is an artifact of scaling to 100% of the sample.

There may be C10-C15 compounds that may be from natural gas (blue bar zone), but they are small portion of the vehicle filter liquid.

Example Regulator Testing

3: Vehicle Post-Pressure Regulation.

Coolant Thermal Input is a Significant Parameter

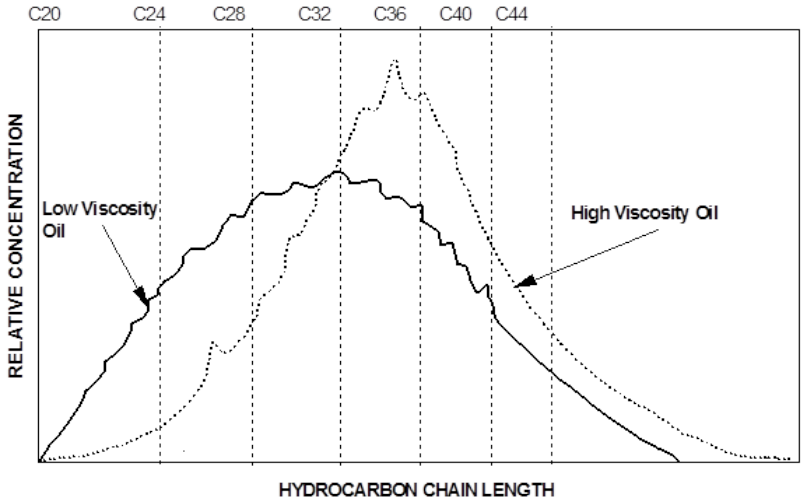
Very cold temperatures are possible due to gas expansion cooling effects

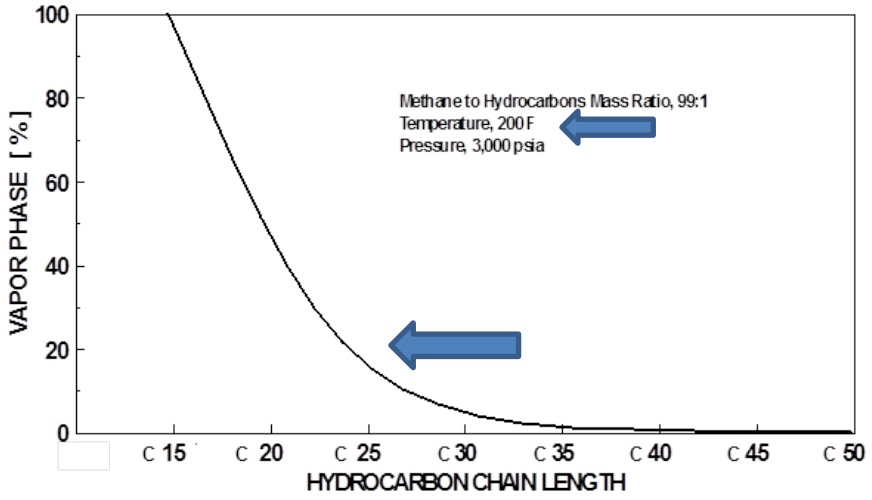
- 60F Ambient
- Flow rates synonymous w/HD engine
- 3000psig tank pressure and 110psig regulator outlet
- Gas temp at outlet of regulator: -40 to -60F

Effective regulator heat input can help mitigate cold temperatures

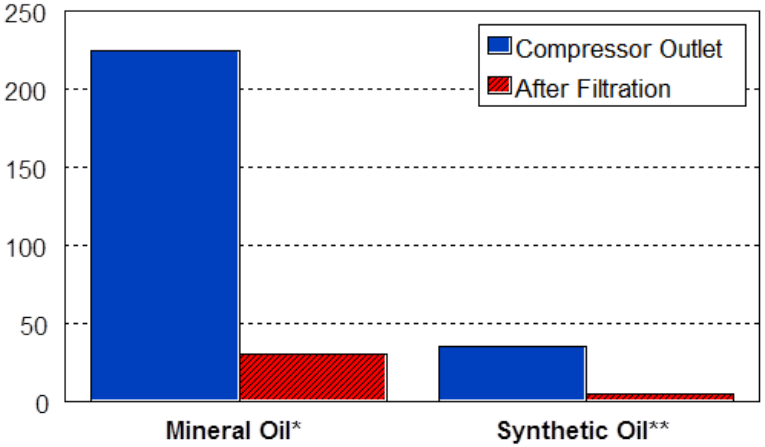
- 180F engine coolant to pre-heat gas
- Gas temp at outlet of regulator: +30 to +40F

Prior GTI Oil Testing Report

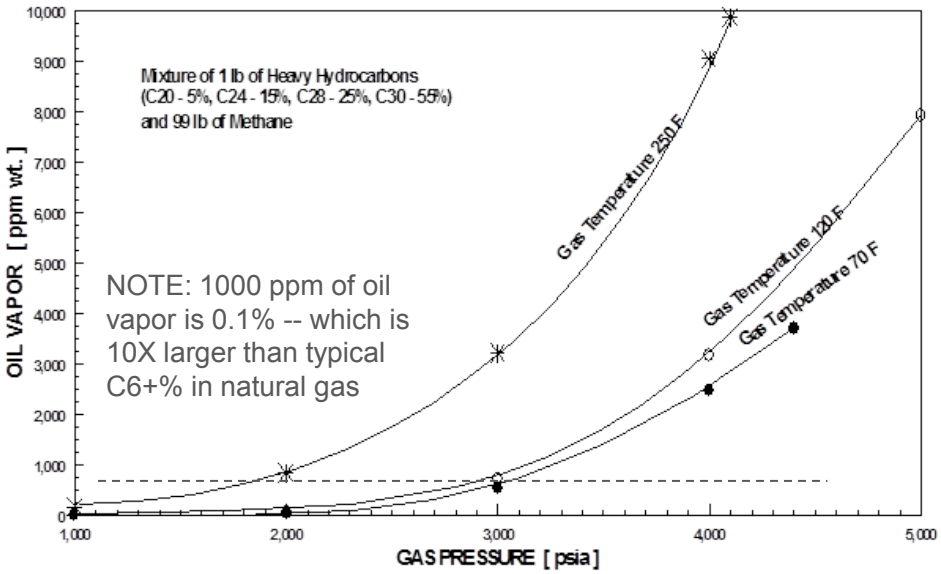




NGV Compressor Oil Carryover



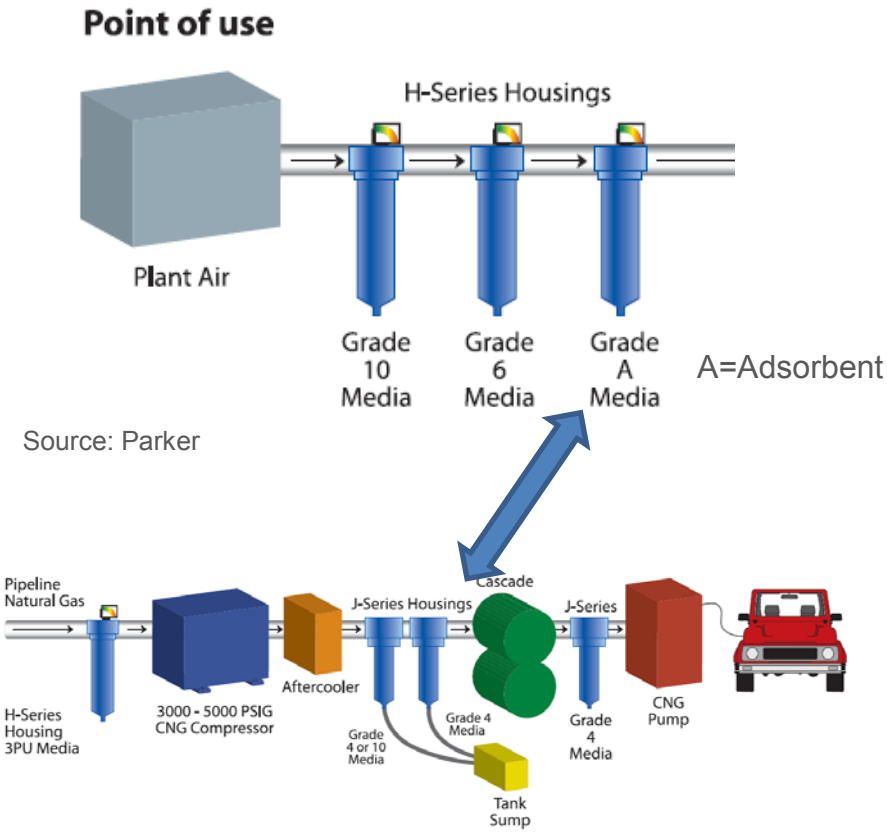
* Mobil DTE Mineral Oil
** Royco 886 Synthetic PAG Oil

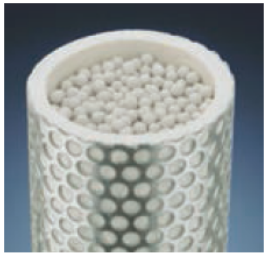


Parameters to increase oil capture: (1) synthetic oil, (2) higher viscosity, (3) lower coalescing filter temperature

Solid Adsorbents, Other Removal Options

- Adsorbents or other options may be feasible to remove trace oil levels or very heavy hydrocarbons
- Likely most effectively applied at fuel station
- Sizing, monitoring, cost, and service issues TBD





Type 10JWA

Vapor adsorbing filter element consisting of a grade 10 microfiber tube, strengthened by a perforated metal retainer and then filled with activated alumina, which works as a desiccant dryer, making the air clean and dry as it exits. This element should always be preceded by a coalescing filter.

For use with:
- J-Series (5000 PSIG)

This filter concept serves as a framework for consideration. Capacity needs to be assessed.

HHCs Issue Summary

- Only limited recent national gas composition survey data is available. Results to date do not indicate any significant negative shifts since prior 1992 survey
- Preliminary (and limited) testing of liquids seems to indicate:
  - The heavier portion of compressor oil is being removed at the station effectively
  - Some lighter portion of comp. oil appears to be showing up in the low-pressure vehicle regulator
- Options to improve station compressor oil/heavy hydrocarbon capture:
  - Using synthetic oil, using higher viscosity oils, lower temperature during filtration, adding an adsorbent or similar add-on device downstream of the coalescing filter
- Options to avoid liquids forming downstream of vehicle pressure regulator:
  - Increase heat transfer into regulator to boost gas temperature to avoid condensation; add-on device using solid adsorbent downstream of coalescing filter
- GTI's Analytical Lab is available to help

Natural Gas Vehicle Fuel Standard (?)

- Current Status
  - SAE J1616 "***Recommended Practice*** for Compressed Natural Gas Vehicle Fuel"
  - Last revised in 1992
  - There is no standard for natural gas vehicle fuel in the US or Canada
  - Natural Gas is "natural", it is not a "refined" product

SAE J1616 Task Force

- SAE J1616 Task Force Creation
  - March 2014, NFPA 52 “Committee on Vehicular Natural Gas Fuel Systems Code” met in Atlanta
  - Committee voted to reduce water content in CNG
  - Committee requested SAE TC #7 issue a new CNG Fuel Standard rather than a Recommended Practice
  - SAE J1616 Task Force created- Bob Petsinger – CNG Services International - Chair

SAE J1616 Task Force

- SAE J1616 -Technical topics addressed in the document (Section 4)
  - Methane Number
  - Wobbe Index
  - Pressure Water Dew Point Temperature
  - Hydrogen Sulfide
  - Carbon Dioxide
  - Methanol Prohibition
  - Oxygen Concentration
  - Natural Gas Odorant
  - Particulate and Foreign Material
  - Oil Content
  - Pressure Hydrocarbon Dew Point Temperature

SAE J1616 Task Force

- Challenges
  - Natural gas supply varies regionally and seasonally
  - Gas composition changes day to day
  - Varying manufacturer/engine specifications lead to varying requirements
  - Station providers “typically” address water and compressor oil carryover but not other natural gas properties
  - Instrumentation for full speciation are complex

SAE J1616 Task Force

- Status
  - Task Force has met several times throughout Summer and Fall 2014
  - Discussions on technical topics (Section 4) has led to creation of smaller working groups
  - Goal is to complete revisions and send document to the SAE TC7 Committee for balloting this year

Closing Thoughts

- Important to 1) cylinder integrity, and 2) Vehicle Fuel System and Engine Performance
- Practicality of a NGV Fuel Standard (?)
  - Where does compliance responsibility fall?
  - What frequency shall quality be verified?
  - Are reasonable methods for measurement or monitoring available?
  - Should we focus on the constituents that can be managed at the station (Comp. Oil, HHCs, Moisture)?